Fill in the Blanks in the Parameter Space of Observational Astronomy

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In observational astronomy, we essentially measure the location, flux density (at certain frequency and certain time), distance and angular size of the sources. A parameter space of observational astronomy can be constructed with the parameters such as the sample size of sources, frequency (bandwidth and frequency resolution), time (observing length and time resolution), sensitivity, and angular resolution of the telescope. Based on the previous experience, we would always obtain new knowledge of the universe with instruments that fill in the blanks in the parameter space, e.g. telescopes used for better surveys (which enlarge the sample sizes of sources), telescopes with higher sensitivity, angular resolution, frequency resolution or time resolution.

In the year of 2022, there has been rapid progress in observational astronomy. Part of blanks in the parameter space has been filled in, with telescopes of higher sensitivity, instruments in a new frequency range, and the larger sample of stars from survey telescopes.

The James Webb Space Telescope (JWST) observations generated images of galaxies (see Figure 1), galaxy clusters, and star forming regions, with unprecedented details compared with that obtained with Hubble Space Telescope (HST). Since JWST observes with unprecedentedly high angular resolution in the infrared band, it reveals structures largely obscured in the optical band of HST. JWST also detected some very high-redshift galaxies for the first time, providing the information of galaxy evolution in the early time.

The largest sample of stars to date measured by the astrometric satellite, Gaia and Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) makes it possible for the first time to study the early formation history of our Milky Way [1].

Following the detection of the photon with energy exceeding 1 PeV for the first time in 2021, Large High Altitude Air Shower Observatory (LHAASO) detected several thousand photons at 18 TeV from a gamma ray burst (GRB), GRB221009A. This is the first time to detect photons with energy exceeding 10

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TeV in a GRB, providing new information about these bursts.

The observations of fast radio bursts (FRBs) with five-hundred-meter aperture spherical radio telescope (FAST) and other telescopes have found that the environment of FRBs is complex, and given constraints to the ambient magnetic field of FRBs [2]. There is hope that we will finally reveal the nature of FRBs soon.

Following the 2021 launched Chinese Hα solar explorer (CHASE, achieving the first ever solar Hα imaging observation from space. See Figure 1 for the image it took), a new space solar satellite, Advanced Space-based Solar Observatory (ASO-S) was launched on 9th, October, 2022. The best quality images and videos from ASO-S will be released in about 6 months and kept being updated.

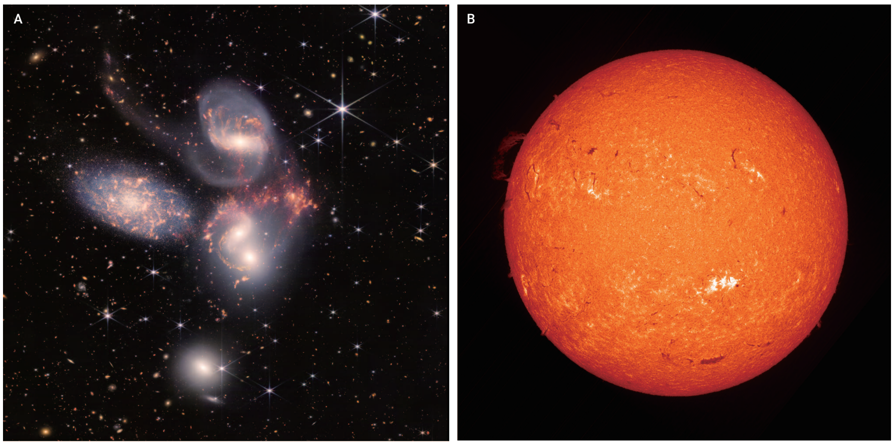

Figure 1: Image of Stephen's quintet obtained with JWST (A: from NASA, ESA, CSA, and STScI). Solar Hα image taken by CHASE (B: from NJU, and CAS). This is the first ever solar Hα imaging observation from space.

Since the universe has a finite age and the speed of light (also other messengers, e.g. neutrino and gravitational wave) is also finite, we can only observe a finite part of the whole universe, i.e., the observable universe. In the observable universe, the number of galaxies is finite. We can only obtain samples with finite number of sources. Due to the uncertainty relation $\Delta\nu \cdot \Delta t \gtrsim 1$ (where we have eliminated the Planck's constant), we can only obtain limited frequency resolution and time resolution simultaneously. The angular resolution is also limited ($\sim$ several micro-arcseconds) because of the scattering of electromagnetic wave by the interstellar medium and the lensing by intervening objects [3]. Apparently, the parameter space of observational astronomy is finite in most dimensions. The possible exception is the observing time.

With the development of sophisticated instruments, we may finally reach the boundary of the parameter space in most dimensions. However, at current stage, there are still large blanks in the parameter space. For example, we have

currently reached the angular resolution limits only in radio band with VLBI technique, while there are still more than 3 orders of magnitude to the limits in the optical, infrared windows and bands of higher energy [3]. In the near future, we should still plan for larger telescopes to fill in the blanks in the parameter space, in order to obtain new knowledge of the universe. Besides larger telescopes, it is also important to build survey telescopes to observe more sources, based on the success of Sloan digital sky survey (SDSS). The atmosphere is only transparent to radio, optical and several infrared bands. We are also facing the challenges from the increasing number of man-made satellites, e.g., starlink. Therefore, large survey space telescopes should be built, in order to achieve the best stability and angular resolution. This is the idea of the Chinese Space Station Telescope (CSST), which will be launched in comming years. Large survey space telescopes in other bands will also help to fill in the blanks in the parameter space.

Even when we finally reach the boundary of the parameter space in most dimensions, we still need to continue our observations. To demonstrate this point, let us look at two examples. First, in the past, humans observe the sky with naked eyes for thousands of years. The parameter space is not explored in most dimensions, but the observing time is getting longer. Numerous transient phenomena, such as novae, supernovae, are recorded with their observations. These records help us determine the exact age of the Crab pulsar. Second, in solar physics, there is only one object to observe. But we are constantly obtaining new insights with continuous observations of the Sun. When we reach the boundary of the parameter space, the paradigm of the traditional observational astronomy would have a change.

The astronomy would become the continuous observations of several objects or even all the observable objects. In the era of constantly monitoring a large number of sources, astronomy will become a "data science". The data storage and access would become the bottleneck of observational astronomy. We should have the ability to conveniently access the data obtained in tens of years, even hundreds of years. Currently, we still lack the corresponding infrastructure and mechanism to support these practices, although we already have virtual observatories (VO). There is still a long way to make this happen.

The astronomy is also possible to become a special kind of chemistry and biology, to study the evolution of molecules and the origin of life. We have already seen this trend in nowadays. When we look at chemistry and biology, we always find endless new states and new patterns of the molecules. Similarly, in a chemical astronomy (astrochemistry) or biological astronomy (astrobiology), the structure of the parameter space would be quite different. We may never go though every corner. There will always be blanks to fill in.

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References

[1] M. Xiang, H.-W. Rix, 2022, A time-resolved picture of our Milky Way's early formation history, Nature, 603 (7902), 599–603. doi:10.1038/s41586-022-04496-5.

[2] H. Xu, J. R. Niu, P. Chen, K. J. Lee, W. W. Zhu, S. Dong, B. Zhang, J. C. Jiang, B. J. Wang, J. W. Xu, C. F. Zhang, H. Fu, A. V. Filippenko, E. W. Peng, D. J. Zhou, Y. K. Zhang, P. Wang, Y. Feng, Y. Li, T. G. Brink, D. Z. Li, W. Lu, Y. P. Yang, R. N. Caballero, C. Cai, M. Z. Chen, Z. G. Dai, S. G. Djorgovski, A. Esamdin, H. Q. Gan, P. Guhathakurta, J. L. Han, L. F. Hao, Y. X. Huang, P. Jiang, C. K. Li, D. Li, H. Li, X. Q. Li, Z. X. Li, Z. Y. Liu, R. Luo, Y. P. Men, C. H. Niu, W. X. Peng, L. Qian, L. M. Song, D. Stern, A. Stockton, J. H. Sun, F. Y. Wang, M. Wang, N. Wang, W. Y. Wang, X. F. Wu, S. Xiao, S. L. Xiong, Y. H. Xu, R. X. Xu, J. Yang, X. Yang, R. Yao, Q. B. Yi, Y. L. Yue, D. J. Yu, W. F. Yu, J. P. Yuan, B. B. Zhang, S. B. Zhang, S. N. Zhang, Y. Zhao, W. K. Zheng, Y. Zhu, J. H. Zou, 2022, A fast radio burst source at a complex magnetized site in a barred galaxy, Nature, 609 (7928), 685–688. doi:10.1038/s41586-022-05071-8.

[3] M. Harwit, 2021, Cosmic Messengers: The Limits of Astronomy in an Unruly Universe, Cambridge University Press.